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(54) A magnetic resonance imaging method and apparatus

Verfahren und Gerät für die Bilderzeugung durch magnetische Resonanz

Méthode et appareil d'imagerie par résonance magnétique

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(56) References cited:
EP-A- 0 498 539
US-A- 5 128 615
US-A- 5 153 517

- **BOOK OF ABSTRACTS OF THE MEETING OF THE SOCIETY OF MAGNETIC RESONANCE IN MEDICINE, SAN FRANCISCO, vol. 1, 1988, page 259 XP000079992 M. MEHDIZADEH ET AL.: "A QUADRATURE PLANAR SURFACE COIL FOR SPINE STUDIES"**

Description

[0001] The present invention relates to a magnetic resonance imaging method and apparatus. It finds particular application in conjunction with magnetic resonance imaging of the spine in permanent C-magnet magnetic resonance imaging systems and will be described with particular reference thereto. However, it is to be appreciated that the present application will also find application in conjunction with other magnetic resonance imaging and spectroscopy systems in which the B_0 primary magnetic field is orthogonal to the plane of the radio frequency coils.

[0002] Conventionally, magnetic resonance imaging procedures include disposing the patient in a substantially uniform, primary magnetic field B_0. Magnetic resonance is excited in dipoles which preferentially align with the B_0 field by transmitting radio frequency excitation signals into the examination region and receiving radio frequency magnetic resonance signals emanating from the resonating dipoles.

[0003] Most commonly, the B_0 field is generated along the central bore of an annular magnet assembly, i.e., the B_0 field aligns with the central axis of the patient. Cylindrical radio frequency and gradient magnetic field coils surround the bore. In order to improve the signal-to-noise ratio, quadrature surface coils have been utilized to examine a region of interest in quadrature, i.e., to receive signal components that are perpendicular to the coil and components that are parallel to the coil. See, for example, U.S. Patent No. 4,918,388 of Mehdizadeh, which illustrates a loop coil and a flat Helmholtz coil, both of which receive resonance signals from the same region. The loop and flat Helmholtz coils are sensitive to orthogonal components of the magnetic resonance signal emanating from dipoles that are aligned with the horizontal magnetic field. When the output of one of the loop and flat Helmholtz coils is shifted by 90° and the two signals are combined, the signal-to-noise ratio is improved by about $\sqrt{2}$.

[0004] In order to examine larger regions of patients disposed in the bore of a horizontal B_0 field imager, surface coils consisting of a plurality of loop coils have also been used. See, for example U.S. Patent No. 4,825,162 of Roemer and Edelstein. More specifically, a series of loop coils are partially overlapped in order to examine contiguous regions. As explained mathematically by Grover in "Inductance Calculations" (1946) and summarized in the Roemer and Edelstein patent, the mutual inductance between adjacent coils is minimized when the coils are positioned by a slight overlap. Although the use of overlapped loop coils with the induction minimized enabled a larger area to be examined, each coil was linear. That is, each coil was sensitive to only one component and not sensitive to the orthogonal component such that no quadrature detection was provided.

[0005] U.S. Patent No. 4,721,913 of Hyde, et al. illustrates another surface coil technique for horizontal field magnets. A series of linear coils are arranged continuous to each other, but with each coil disposed 90° out-of-phase with adjacent coils. Thus, each coil received a radio frequency magnetic resonance signal component that was orthogonal to its neighbors.

[0006] In U.S. Patent No. 5,394,087 of Molyneaux, a loop and flat Helmholtz coil are superimposed to provide a flat quadrature coil. A plurality of these flat quadrature coils are partially overlapped to define a planar, quadrature coil array.

[0007] While the above-referenced surface coils are effective for horizontal B_0 field magnetic resonance imaging equipment, all magnetic resonance imaging equipment does not employ a horizontal B_0 field. C-magnet magnetic resonance imagers include a pair of parallel disposed pole pieces which are interconnected by a C or U-shaped iron element. The iron element may be a permanent magnet or can be electrically stimulated by encircling coils to a magnetic condition. Typically, the pole pieces are positioned horizontally such that a vertical field is created in between. Thus, in an annular bore magnetic field imager, the B_0 field extends between the patient's head and feet (or feet and head); whereas, in a C-shaped magnet the B_0 magnetic field extends between a patient's back and front (or front and back). Due to the 90° rotation of the B_0 field, quadrature surface coils such as illustrated in the above-referenced U.S. Patent No. 5,394,087, when positioned along the patient's spine in a vertical B_0 field magnetic resonance imager, would not function in quadrature. They would lose sensitivity to one of their modes. A resonator for examining a particular region of a patient in the field of such a magnet has been proposed (US-A-5 153 517), which uses quadrature signal take-offs between electrically conductive connecting elements connected to 180° opposite points, offset by 90° from each other, on an electrically conductive loop.

[0008] The present invention provides a new and improved radio frequency coil that provides quadrature reception/transmission in vertical B_0 field magnets.

[0009] The invention provides a magnetic resonance imaging system which includes a pair of generally horizontal magnet pole pieces between which a vertical, temporally constant B_0 magnetic field is defined, a generally C-shaped ferrous flux path connecting the pole pieces, gradient magnetic field coils disposed adjacent the pole pieces for causing gradient magnetic fields across the temporally constant B_0 magnetic field, a means for exciting resonance in selected dipoles in between the pole faces such that the dipoles generate resonance signals about a characteristic resonance frequency, a radio frequency coil assembly for receiving resonance signals from the resonating dipoles, at least one radio frequency receiver for demodulating the resonance signals from the radio frequency coil, and a reconstruction processor for reconstructing the demodulated radio frequency signals into an image representation, and wherein the radio frequency coil assembly in-

cludes:

a first electrically conductive loop;
a first signal take-off point between electrically conductive connecting elements extending between a first pair of 180° opposite points of the first electrically conductive loop;
a second signal take-off point between electrically conductive connecting elements connected between a second pair of 180° opposite points on the first electrically conductive loop, which second pair of 180° opposite points on the first electrically conductive loop are substantially 90° offset from the first pair of 180° opposite points, such that the resonance signals from the first and second signal take-off points are substantially 90° out-of-phase in a quadrature relationship, the first and second signal take-off points being connected via electrical leads with the receiver, characterised by a second electrically conductive loop which partially overlaps the first electrically conductive loop.

[0010] One advantage of the present invention is that it provides quadrature detection over an extended region of the anatomy on vertical field systems.

[0011] Another advantage of the present invention is that it simultaneously receives in quadrature for improved signal-to-noise and reduced acquisition time.

[0012] Another advantage of the present invention is that it may be contoured to the anatomical area of interest.

[0013] The invention will now be further described by way of example with reference to the accompanying drawings in which:

FIGURE 1 is a diagrammatic illustration of a magnetic resonance system in accordance with the present invention;
FIGURE 2 is an enlarged view of the coil assembly of FIGURE 1;
FIGURE 3 illustrates a technique for trueing the orthogonality of the components of a single coil;
FIGURE 4 illustrates a technique for adjusting the mutual inductance of two or more coils;
FIGURE 5 illustrates another technique for adjusting the coils to minimize their mutual inductance;
FIGURE 6 illustrates yet another technique for minimizing the mutual inductance of the coils;
FIGURE 7 is a schematic representation of the coil array of FIGURE 2 in which the quadrature components are combined at the coil;
FIGURE 8 is a schematic representation of the coil array of FIGURE 2 in which the signals from each coil are processed individually;
FIGURE 9 illustrates an alternate embodiment in which the coils are non-planar to accommodate patient anatomy;
FIGURE 10 illustrates another alternate embodiment in which the coils are non-planar to accommodate patient anatomy;
FIGURE 11 is another alternate embodiment in which two parallel arrays are provided on opposite sides of the patient for volume imaging;
FIGURE 12 illustrates another alternate embodiment of the present invention with four modes;
FIGURE 13 illustrates another alternate embodiment with a pair of double-D coils; and,
FIGURE 14 illustrates another alternate embodiment with a pair of orthogonal Figure-8 coils.

[0014] With reference to FIGURE 1, an imaging region **10** is defined between pole pieces **12, 14.** The pole pieces are interconnected by a ferrous flux path **16**, such as a C or U-shaped iron element. In a preferred embodiment, the iron element **16** is a permanent magnet which causes a vertical B_0 magnetic field between the pole faces across the imaging region. Alternately, electrical windings may be provided for inducing the magnetic flux in the ferrous flux path **16** and the B_0 field across the pole faces. Passive or active shims are disposed at the pole pieces or in the ferrous flux path adjacent the pole pieces to render the vertical B_0 field more linear across the imaging region **10.**

[0015] For imaging, magnetic field gradient coils **20, 22** are disposed at the pole pieces **12, 14.** In the preferred embodiment, the gradient coils are planar coil constructions which are connected by gradient amplifiers **24** to a gradient magnetic field controller **26.** The gradient magnetic field controller, as is known in the art, causes current pulses which are applied to the gradient coils such that gradients in the uniform magnetic field are created along the longitudinal or z-axis, the vertical or y-axis, and the transverse or x-axis.

[0016] In order to excite magnetic resonance in dipoles of a subject disposed in the examination region **10**, radio frequency coils **30, 32** are disposed between the gradient coils and the imaging region. A radio frequency transmitter **34**, preferably a digital transmitter, causes the radio frequency coils to transmit radio frequency pulses requested by a radio frequency pulse controller **36** to be transmitted into the imaging region **10.** A sequence controller **40**, under operator control, retrieves an imaging sequence from a sequence memory **42.** The sequence controller **40** provides the sequence information to the gradient controller **26** and the radio frequency pulse controller **36** such that radio frequency and gradient magnetic field pulses in accordance with the selected sequence are generated.

[0017] A radio frequency surface coil assembly **50** is disposed along a region of interest of the subject. Typically, the radio frequency coils **30, 32** are general purpose coils and are built-in. On the other hand, specialty surface coils are removable for greater flexibility. However, the surface coil **50** and the below-described alternate embodiments can be the only radio frequency coils in the system. In the embodiment of FIGURE 1, the sur-

face coil assembly **50** is an elongated spine coil that is disposed on a patient supporting surface immediately below the spinal column of a patient resting on the patient supporting surface. The surface coil assembly **50** with radio frequency receivers **52** demodulates the radio frequency resonance signals received by the built-in and/or removable radio frequency coils. As is explained in greater detail below in conjunction with FIGURES 3 and 4, the surface coil assembly **50** is an array of coils, each connected with one or more receivers **52.** Signals from the receivers are digitized with an array of analog-to-digital converters **54** and processed by a reconstruction processor **56** into volumetric image representations which are stored in a volumetric image memory **58.** A video processor **59**, under operator control, withdraws selected image data from the volume memory and formats it into appropriate format for display on a human-readable display **61**, such as a video monitor, active-matrix monitor, liquid crystal display, or the like.

[0018] With reference to FIGURE 2, the coil array **50** has a plurality of window pane coils $\mathbf{50_1}$, $\mathbf{50_2}$, etc. of like construction. Each of the window pane coils has two modes, one in the x-direction and one in the z-direction. More specifically, each window pane coil includes a peripheral loop **60** which, in the illustrated embodiment, has four legs or segments $\mathbf{60_1}$, $\mathbf{60_2}$, $\mathbf{60_3}$, **and** $\mathbf{60_4}$ of equal length which are disposed in an orthogonal pattern to define a square. A first cross-member $\mathbf{62_1}$ is connected to oppositely disposed, 180° opposite points on the peripheral loop, specifically to the center of oppositely disposed peripheral elements $\mathbf{60_1}$ and $\mathbf{60_3}$. Signal take-off points $\mathbf{64_1}$ are connected by leads from the first cross-member to the receivers **52**. A second cross-member $\mathbf{62_2}$ is connected to 180° opposite connection points on the outer loop that are 90° offset with respect to the first cross-member connection points, particularly to the central point of opposite legs $\mathbf{60_2}$ and $\mathbf{60_4}$. The two cross-members $\mathbf{62_1}$ and $\mathbf{62_2}$ cross perpendicular to each other but are not connected to each other. A second pair of take-off points $\mathbf{64_2}$ on the second cross-member $\mathbf{62_2}$ are connected by leads with the receivers **52.** Each of the window pane coils $\mathbf{52_1}$, $\mathbf{52_2}$, etc. has analogous coil take-offs. The coil defined by the cross-member $\mathbf{62_1}$ an the loop coil **60** receives radio frequency signals with a polarity $\mathbf{66_x}$. By distinction, the coil defined by the loop coil 60 and the cross-member $\mathbf{62_2}$ is sensitive to radio frequency signal components $\mathbf{66_z}$, which extend in the z-direction. Capacitors are added as necessary to tune the coils such that the first pair of connection points are at a virtual ground with respect to the second take-off points and the second pair of connection points is at a virtual ground with respect to the first take-off points.

[0019] For a two-coil construction, there are thus four modes - two x-modes and two z-modes. The x-modes and z-modes within each coil are orthogonal to each other and have minimum mutual inductance due to the symmetry. Alternately, as shown in FIGURE 3, a reactive element can be connected between cross-members to adjust the orthogonality of the modes, particularly when the above-discussed symmetry is lacking. Analogously, the x-mode in one coil and the z-mode in the other coil are orthogonal and have minimal mutual inductance due to the symmetry. The coils are overlapped such that the x-modes between two adjacent coils have a minimum mutual inductance due to spatial position. Preferably, the z-modes of the two coils also have minimum mutual inductance at the overlap.

[0020] With reference to FIGURE 4, the two coils are overlapped until the x-modes have a minimum mutual inductance. If the z-modes do not have a minimum mutual inductance at this point, a reactive element **70** is added for changing the current distribution of the z-mode of one or both coils until minimum mutual inductance is achieved. Alternately, as illustrated in FIGURE 5, a reactive element **72** can be placed between the two coils to feed current between the coils to achieve minimum mutual inductance. The reactance **72** can be between the z-mode cross-members to minimize the mutual inductance between the z-modes. As yet another alternative, as illustrated in FIGURE 6, the dimension of one or both of the coils in the z-direction can be extended or contracted to achieve mutual minimum inductance by changing geometry.

[0021] With reference to FIGURE 7, the x and z-orthogonal coil leads from coil $\mathbf{50_1}$ are connected independently with a pair of matching circuits $\mathbf{80_x}$ and $\mathbf{80_z}$. Analogously, the x and z-mode coils of the window pane coil $\mathbf{50_3}$ are connected with matching circuits $\mathbf{82_x}$ and $\mathbf{82_z}$. Some or all of the capacitors or other reactive elements of the circuits **80, 82** can be incorporated into the coil 50. The x and z-components of the window pane coil $\mathbf{50_1}$ are 90° phase-shifted and combined by a phase-shifter and combiner circuit 84. Analogously, the x and z-components of the window pane coil $\mathbf{50_2}$ are 90° phase-shifted and combined by a phase-shifter and combiner **86**. The combined, unitary output from each of the coils $\mathbf{50_1}$, $\mathbf{50_2}$, etc. are connected with amplifiers $\mathbf{88_1}$, $\mathbf{88_2}$. Preferably, the amplifiers are mounted at the coil assembly. The plurality of receivers **52** includes a receiver $\mathbf{52_1}$ for demodulating the combined signal from coil $\mathbf{50_1}$ and a second receiver $\mathbf{52_2}$ for demodulating the combined output signal from coil $\mathbf{50_2}$. The analog-to-digital converter array **54** includes an analog-to-digital converter $\mathbf{54_1}$ for digitizing the output of receiver $\mathbf{52_1}$ and an analog-to-digital converter $\mathbf{54_2}$ for digitizing the output of the radio frequency receiver $\mathbf{52_2}$.

[0022] With reference to FIGURE 8, the output of each component of the coils can be demodulated individually. More specifically, the x and z-components of coil $\mathbf{50_1}$ are again conveyed to matching circuits $\mathbf{80_x}$' and $\mathbf{80_z}$' while the x and z-components of coil $\mathbf{50_2}$ are conveyed to matching circuits $\mathbf{82_x}$' and $\mathbf{82_z}$'. The outputs of the matching circuits are conveyed to individual preamplifiers $\mathbf{90_1}$, $\mathbf{90_2}$, $\mathbf{90_3}$, and $\mathbf{90_4}$. The array of receivers **52** includes individual receivers $\mathbf{92_1}$, $\mathbf{92_2}$, $\mathbf{92_3}$, and $\mathbf{92_4}$ for

demodulating each of the x and z-components. Analogously, the analog-to-digital converter array **54** includes individual analog-to-digital converters **94_1**, **94_2**, **94_3**, **94_4** for digitizing each of the components. These signals may be combined in digital form analogous to the combiner of FIGURE 7 or used in other types of processing as are known in the art. As yet another alternative, the resonance signals can be digitized on the surface coil assembly and demodulated by a digital receiver.

[0023] With reference to FIGURE 9, the window pane coils may be non-planar to conform with portions of the patient's anatomy. For example, the cross-members may extend out of the plane, symmetrically, such as to follow the contours of the patient's breasts for breast imaging. In the embodiment of FIGURE 10, portions of the exterior loop coil are raised out of the plane to provide better coverage of the patient's neck, for example. As yet another alternative, the coils may be disposed along an arcuate curve.

[0024] With reference to FIGURE 11, a pair of arrays can be positioned on opposite surfaces of the patient to surround the imaging volume more completely. The FIGURE 11 embodiment is well-adapted to be built into the pole pieces as the standard whole volume radio frequency coils.

[0025] With reference to FIGURE 12, the cross-members of the window pane coil can be connected at a central point 100. This provides a coil with two additional modes. In particular, when the window pane coil is symmetric, the two extra modes are at 45° relative to the x and z-modes and at a higher frequency. This enables the coil to be doubly-tuned for multi-channel spectroscopy imaging. As indicated above, although the window pane coil is preferably symmetric, it need not be. Reactive elements may be provided between the modes to adjust their relative orthogonality.

[0026] As illustrated in FIGURE 13, each of the window pane coils **50_1**, **50_2**, etc. may be built from a pair of analogous double-D or butterfly coils rotated 90° relative to each other. In the FIGURE 13 embodiment, coil **50_1** includes a first double-D coil **110** having take-off points **112** and a second double-D coil **114** having take-off points **116**. These assemblies can again be overlapped to form arrays and can have added reactive elements to adjust orthogonality. As illustrated in FIGURE 14, the window pane coils can be approximated by a pair of Figure-8 or double-diamond coils **120, 122.** The coils again have substantially linear segments that cross perpendicular to each other, without connecting. The coils can again be overlapped in arrays, preferably with its outer loop portion square or rectangular.

Claims

1. A magnetic resonance imaging system which includes a pair of generally horizontal magnet pole pieces (12, 14) between which a vertical, temporally constant B_0 magnetic field is defined, a generally C-shaped ferrous flux path (16) connecting the pole pieces (12, 14), gradient magnetic field coils (20, 22) disposed adjacent the pole pieces (12, 14) for causing gradient magnetic fields across the temporally constant B_0 magnetic field, a means for exciting resonance in selected dipoles in between the pole faces such that the dipoles generate resonance signals about a characteristic resonance frequency, a radio frequency coil assembly (50) for receiving resonance signals from the resonating dipoles, at least one radio frequency receiver (52) for demodulating the resonance signals from the radio frequency coil, and a reconstruction processor (56) for reconstructing the demodulated radio frequency signals into an image representation, and wherein the radio frequency coil assembly includes:

   a first electrically conductive loop (60, 50_1);
   a first signal take-off point (64_1) between electrically conductive connecting elements (62_1) extending between a first pair of 180° opposite points of the first electrically conductive loop;
   a second signal take-off point (64_2) between electrically conductive connecting elements (62_2) connected between a second pair of 180° opposite points on the first electrically conductive loop (60, 50_1), which second pair of 180° opposite points on the first electrically conductive loop (60, 50_1) are substantially 90° offset from the first pair of 180° opposite points, such that the resonance signals from the first and second signal take-off points (64, 62_2) are substantially 90° out-of-phase in a quadrature relationship, the first and second signal take-off points (64_1, 62_2) being connected via electrical leads with the receiver, **characterised by** a second electrically conductive loop (50_2) which partially overlaps the first electrically conductive loop (50_1).

2. A magnetic resonance imaging apparatus as claimed in claim 1, further including:

   a third signal take-off point between electrically conductive connecting elements which extend between a third pair of 180° opposite points of the second electrically conductive loop (50_2) ; and
   a fourth signal take-off point between electrically conductive connecting elements connected between a fourth pair of 180° opposite points on the second electrically conductive loop, which fourth 180° opposite points on the loop are substantially 90° offset from the third pair of 180° opposite points.

3. A magnetic resonance imaging system as claimed

in claim 1 or claim 2, wherein the first electrically conductive loop (60, 50_1) and the first and second electrically conductive connecting elements (62_1, 62_2) all lie substantially in a common plane.

4. A magnetic resonance imaging system as claimed in any one of the preceding claims, wherein the first electrically conductive loop (60, 50_1) is square with the first 180° opposite points being disposed at mid-points of first opposite sides (60_1, 60_3) of the square and the second 180° opposite points being disposed at mid-points of second opposite sides (60_2, 60_4) of the square.

5. A magnetic resonance imaging system as claimed in claim 4, wherein mid-points of the first and second electrically conductive connecting elements (62_1, 62_2) are connected to define four symmetric interconnecting segments, each of the interconnecting segments being connected with the at least one radio frequency receiver such that the coil supports four modes 45° apart.

6. A magnetic resonance imaging apparatus as claimed in claim 1, wherein the first electrically conductive loop and the first and second electrically conductive connecting elements are formed from a pair of butterfly coils or a pair of figure of eight coils

7. A magnetic resonance imaging method which includes generating a vertical, temporally constant B_0 magnetic field, selectively generating gradient magnetic fields across the temporally constant B_0 magnetic field, exciting resonance in selected dipoles disposed within the B_0 magnetic field at a characteristic resonance frequency, receiving the resonance signals from the resonating dipoles, demodulating the received resonance signals, and reconstructing the demodulated radio frequency signals into an image representation, including receiving the magnetic resonance signals with a radio frequency coil assembly formed by connecting a first signal take-off point (64_1, 64_2) between electrically conductive elements (62_1) between a pair of 180° opposite points of a first electrically conductive loop (60, 50_1), and connecting a second signal take-off point (64, 64_2) between electrically conductive elements (62_2) between a second pair of 180° opposite points on the electrically conductive loop with the second pair of 180° opposite points being 90° offset from the first pair, such that resonance signal components demodulated from the first and second signal take-off points are substantially 90° out-of-phase in a quadrature relationship, **characterised by** the step of including in said coil assembly a second electrically conductive loop which partially overlaps the first electrically conductive loop.

8. A method as claimed in claim 7, including arranging the electrically conductive loops and the first and second electrically conductive elements substantially in a common plane and positioning the radio frequency coil in the B_0 magnetic field with the common plane substantially perpendicular to the B_0 field.

Patentansprüche

1. Magnetresonanz-Bildgebungssystem mit: einem Paar allgemein horizontaler Magnetpolstücke (12, 14), zwischen denen ein vertikales, temporär konstantes B_0-Magnetfeld definierte ist; einem allgemein C-förmigen Eisenflussweg (16), der die Polstücke (12, 14) miteinander verbindet; Gradientenmagnetfeldspulen (20, 22), die neben den Polstükken (12, 14) angeordnet sind, um Gradientenmagnetfelder über das temporär konstante B_0-Magnetfeld zu bewirken; einem Mittel zur Anregung von Resonanz in ausgewählten Dipolen zwischen den Polseiten, so dass die Dipole Resonanzsignale um eine charakteristische Resonanzfrequenz erzeugen; einer Hochfrequenzspulenanordnung (50) für den Empfang von Resonanzsignalen der schwingenden Dipole; mindestens einem Hochfrequenzempfänger (52) für die Demodulation der Resonanzsignale von der Hochfrequenzspule; und einem Rekonstruktionsprozessor (56) für die Rekonstruktion der demodulierten Hochfrequenzsignale zu einer Bilddarstellung, wobei die Hochfrequenzspulenanordnung Folgendes umfasst:

eine erste elektrisch leitfähige Schleife (60, 50_1);
einen ersten Signalabgriffspunkt (64_1) zwischen elektrisch leitfähigen Verbindungselementen (62_1), die sich in einem ersten Paar von um 180° gegenüberliegenden Punkten der ersten elektrisch leitfähigen Schleife erstrecken;
einen zweiten Signalabgriffspunkt (64_2) zwischen elektrisch leitfähigen Verbindungselementen (62_2), die zwischen ein zweites Paar von um 180° gegenüberliegenden Punkten an der ersten elektrisch leitfähigen Schleife (60, 50_1) geschaltet sind, wobei das zweite Paar der um 180° gegenüberliegenden Punkten auf der ersten elektrisch leitfähigen Schleife (60, 50_1) im Wesentlichen um 90° versetzt vom ersten Paar der um 180° gegenüberliegenden Punkten angeordnet ist, so dass die Resonanzsignale von dem ersten und dem zweiten Signalabgriffspunkt (64_1, 64_2) im Wesentlichen um 90° in einer Quadraturbeziehung phasenverschoben sind, wobei der erste und der zweite Signalabgriffspunkt (64_1, 64_2) über elektrische Leitungen mit dem Empfänger verbunden sind,

gekennzeichnet durch eine zweite elektrisch leitfähige Schleife (50_2), die die erste elektrisch leitfähige Schleife (50_1) teilweise überlappt.

2. Magnetresonanz-Bildgebungsvorrichtung nach Anspruch 1, die weiterhin Folgendes umfasst:

   einen dritten Signalabgriffspunkt zwischen elektrisch leitfähigen Verbindungselementen, die sich zwischen einem dritten Paar der um 180° gegenüberliegenden Punkten der zweiten elektrisch leitfähigen Schleife (50_2) erstrecken; und

   einen vierten Signalabgriffspunkt zwischen elektrisch leitfähigen Verbindungselementen, die zwischen ein viertes Paar von um 180° gegenüberliegenden Punkten der zweiten elektrisch leitfähigen Schleife geschaltet sind, wobei das vierte Paar der um 180° gegenüberliegenden Punkte an der Schleife im Wesentlichen um 90° versetzt vom dritten Paar der um 180° gegenüberliegenden Punkten angeordnet ist.

3. Magnetresonanz-Bildgebungssystem nach Anspruch 1 oder 2, wobei die erste elektrisch leitfähige Schleife (60, 50_1) und die ersten und zweiten elektrisch leitfähigen Verbindungselemente (62_1, 62_2) alle im Wesentlichen auf einer gemeinsamen Ebene liegen.

4. Magnetresonanz-Bildgebungssystem nach einem der vorhergehenden Ansprüche, wobei die erste elektrisch leitfähige Schleife (60, 50_1) quadratisch ist, wobei die ersten der um 180° gegenüberliegenden Punkte an Mittelpunkten der ersten gegenüberliegenden Seiten (60_1, 60_3) des Quadrates angeordnet sind und die zweiten, um 180° gegenüberliegenden Punkte an Mittelpunkten der zweiten gegenüberliegenden Seiten (60_2, 60_4) des Quadrats angeordnet sind.

5. Magnetresonanz-Bildgebungssystem nach Anspruch 4, wobei die Mittelpunkte der ersten und zweiten elektrisch leitfähigen Verbindungselemente (62_1, 62_2) verbunden sind, um vier symmetrisch miteinander verbundene Segmente zu definieren, wobei jedes der miteinander verbundenen Segmente mit dem mindestens einen Hochfrequenzempfänger verbunden ist, so dass die Spule vier um 45° voneinander getrennte Moden unterstützt.

6. Magnetresonanz-Bildgebungssystem nach Anspruch 1, wobei die erste elektrisch leitfähige Schleife und die ersten und zweiten elektrisch leitfähigen Verbindungselemente durch ein Paar von schmetterlingsförmigen Spulen oder ein Paar von Spulen in Form der Ziffer 8 gebildet werden.

7. MagnetresonanzBildgebungsverfahren, das Folgendes umfasst: Erzeugen eines vertikalen, temporär konstanten B_0-Magnetfelds; selektives Erzeugen von Gradientenmagnetfeldern über dem temporär konstanten B_0-Magnetfeld; Erregen einer Resonanz in ausgewählten Dipolen innerhalb des B_0-Magnetfelds bei einer charakteristischen Resonanzfrequenz; Empfangen der Resonanzsignale von den schwingenden Dipolen;, Demodulieren der empfangenen Resonanzsignale; und Rekonstruieren der demodulierten Hochfrequenzsignale zu einer Bilddarstellung; und das ferner Folgendes umfassend: Empfangen der Magnetresonanzsignale mit einer Hochfrequenzspulenanordnung, die durch die Verbindung eines ersten Signalabgriffspunkts (64_1, 64_2) zwischen elektrisch leitfähigen Elementen (62_1) zwischen einem Paar von um 180° gegenüberliegenden Punkten einer ersten elektrisch leitfähigen Schleife (60, 50) und durch die Verbindung eines zweiten Signalabgriffspunkts (64_3, 64_4) zwischen elektrisch leitfähigen Elementen (62_2) zwischen einem zweiten Paar von um 180° gegenüberliegenden Punkten an der ersten elektrisch leitfähigen Schleife gebildet wird, wobei das zweite Paar der um 180° gegenüberliegenden Punkte um 90° vom ersten Paar versetzt angeordnet ist, so dass Resonanzsignalkomponenten, die von dem ersten und dem zweiten Signalabgriffspunkt demoduliert werden, im Wesentlichen um 90° in einer Quadraturbeziehung phasenverschoben sind, **gekennzeichnet durch** den Schritt, dass in der Spulenanordnung eine zweite elektrisch leitfähige Schleife vorgesehen wird, die die erste elektrisch leitfähige Schleife teilweise überlappt.

8. Verfahren nach Anspruch 7, einschließlich des Anordnens von elektrisch leitfähigen Schleifen und der ersten und zweiten elektrisch leitfähigen Verbindungselemente in einer im Wesentlichen gemeinsamen Ebene, und des Positionierens der Hochfrequenzspule in dem B_0-Magnetfeld auf eine solche Weise, dass die gemeinsame Ebene im Wesentlichen rechtwinklig zu dem B_0-Feld liegt.

Revendications

1. Système d'imagerie par résonance magnétique qui comporte une paire de pièces polaires d'aimant généralement horizontales (12, 14) entre lesquelles un champ magnétique B_0 temporellement constant et vertical est défini, un trajet de flux ferreux (16) généralement en forme de C reliant les pièces polaires (12, 14), des bobines de champ magnétique à gradient (20, 22) qui sont disposées d'une manière contiguë aux pièces polaires (12, 14) pour créer des champs magnétiques à gradient à travers le champ magnétique B_0 temporellement constant,

des moyens pour exciter une résonance dans des dipôles sélectionnés entre les faces polaires de telle façon que les dipôles génèrent des signaux de résonance autour d'une fréquence de résonance caractéristique, un ensemble de bobines à haute fréquence (50) pour recevoir des signaux de résonance en provenance des dipôles résonnants, au moins un récepteur à haute fréquence (52) pour démoduler les signaux de résonance en provenance de la bobine à haute fréquence, et un processeur de reconstitution (56) pour reconstituer les signaux à haute fréquence démodulés en une représentation vidéo, et dans lequel l'ensemble de bobines à haute fréquence comporte:

une première boucle électriquement conductrice (60, 50_1);
un premier point d'extraction de signal (64_1) entre des éléments de connexion électriquement conducteurs (62_1) s'étendant entre une première paire de points opposés à 180° de la première boucle électriquement conductrice;
un deuxième point d'extraction de signal (64_2) entre des éléments électriquement conducteurs (62_2) qui sont connectés entre une deuxième paire de points opposés à 180° sur la première boucle électriquement conductrice (60, 50_1), lequel deuxième de points opposés à 180° sur la première boucle électriquement conductrice (60, 50_1) est sensiblement décalée de 90° par rapport à la première paire de points opposés à 180° de telle façon que les signaux de résonance en provenance des premier et deuxième points d'extraction de signal (64, 64_2) soient sensiblement déphasés de 90° selon une relation en quadrature, les premiers et deuxièmes points d'extraction de signal (64_1, 64_2) étant connectés par l'intermédiaire de fils conducteurs électriques au récepteur, **caractérisé par** une deuxième boucle électriquement conductrice (50_2) qui chevauche partiellement la première boucle électriquement conductrice (50_1).

2. Dispositif d'imagerie par résonance magnétique selon la revendication 1, comportant encore:

un troisième point d'extraction de signal entre des éléments de connexion électriquement conducteurs qui s'étendent entre une troisième paire de points opposés à 180° de la deuxième boucle électriquement conductrice (50_2); et
un quatrième point d'extraction de signal entre des éléments de connexion électriquement conducteurs qui sont connectés entre une quatrième paire de points opposés à 180° sur la deuxième boucle électriquement conductrice, lesquels quatrièmes points opposés à 180° sur la boucle sont sensiblement décalés de 90° par rapport à la troisième paire de points opposés à 180°.

3. Système d'imagerie par résonance magnétique selon la revendication 1 ou 2, dans lequel la première boucle électriquement conductrice (60, 50_1) et les premiers et deuxièmes éléments de connexion électriquement conducteurs (62_1, 62_2) se situent tous sensiblement dans un plan commun.

4. Système d'imagerie par résonance magnétique selon l'une quelconque des revendications précédentes, dans lequel la première boucle électriquement conductrice (60, 50_1) est carrée, les premiers points opposés à 180° étant disposés au niveau de points médians de premiers côtés opposés (60_1, 60_3) du carré et les deuxièmes points opposés à 180° étant disposés au niveau de points médians de deuxièmes côtés opposés (60_2, 60_4) du carré.

5. Système d'imagerie par résonance magnétique selon la revendication 4, dans lequel des points médians des premiers et deuxièmes éléments de connexion électriquement conducteurs (62_1, 62_2) sont connectés pour définir quatre segments d'interconnexion symétriques, chacun des segments d'interconnexion étant connecté à le au moins un récepteur à haute fréquence de telle façon que la bobine supporte quatre modes étant espacés de 45°.

6. Appareil d'imagerie par résonance magnétique selon la revendication 1, dans lequel la première boucle électriquement conductrice et les premiers et deuxièmes éléments de connexion électriquement conducteurs sont formés à partir d'une paire de bobines en forme de papillon ou à partir d'une paire de bobines en forme de huit.

7. Procédé d'imagerie par résonance magnétique qui comprend la génération d'un champ magnétique B_0 temporellement constant et vertical, la génération sélective de champs magnétiques à gradient à travers le champ magnétique B_0 temporellement constant, l'excitation d'une résonance dans des dipôles sélectionnés qui sont disposés dans le champ magnétique B_0 à une fréquence de résonance magnétique, la réception des signaux de résonance en provenance des dipôles résonnants, la démodulation des signaux de résonance reçus et la reconstitution des signaux à haute fréquence démodulés en une représentation vidéo, comprenant la réception des signaux de résonance magnétique à l'aide d'un ensemble de bobines à haute fréquence qui est formé en connectant un premier point d'extraction de signal (64_1, 64_2) entre des éléments électriquement conducteurs (62_1) entre une paire de points opposés à 180° d'une première boucle élec-

triquement conductrice (60, 50_1), et la connexion d'un deuxième point d'extraction de signal (64, 64_2) entre des éléments électriquement conducteurs (62_2) entre une deuxième paire de points opposés à 180° sur la boucle électriquement conductrice, la deuxième paire de points opposés à 180° étant décalée de 90° par rapport à la première paire de telle façon que les composantes de signal qui sont démodulées à partir des premier et deuxième points d'extraction de signal soient sensiblement déphasées de 90° selon une relation en quadrature, **caractérisé par** l'étape consistant à inclure dans ledit ensemble de bobines une deuxième boucle électriquement conductrice qui chevauche partiellement la première boucle électriquement conductrice.

8. Procédé selon la revendication 7, comprenant l'agencement des boucles électriquement conductrices et des premiers et deuxièmes éléments électriquement conducteurs sensiblement dans un plan commun et le positionnement de la bobine à haute fréquence dans le champ magnétique B_0 avec le plan commun sensiblement perpendiculaire au champ B_0.

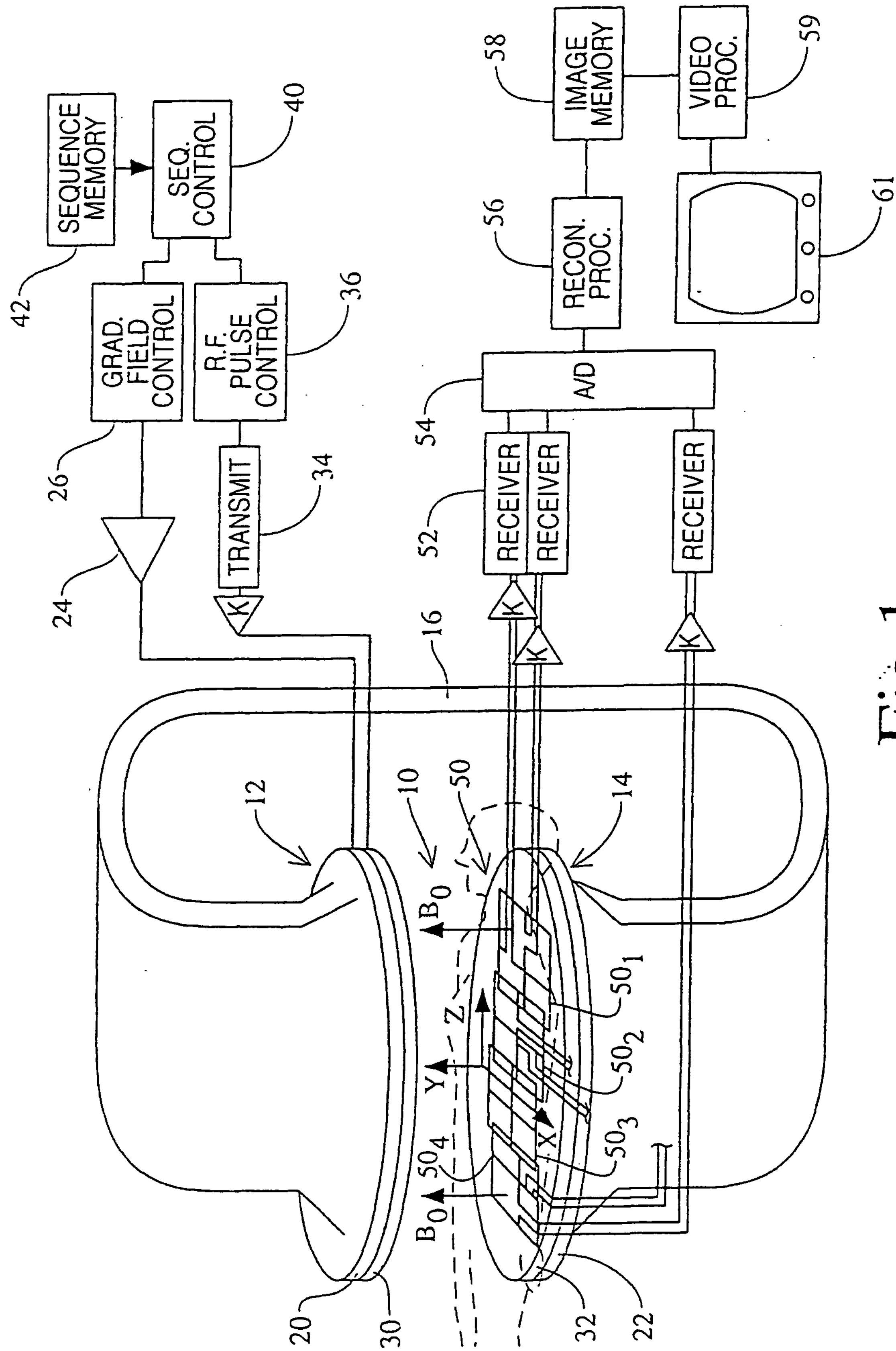
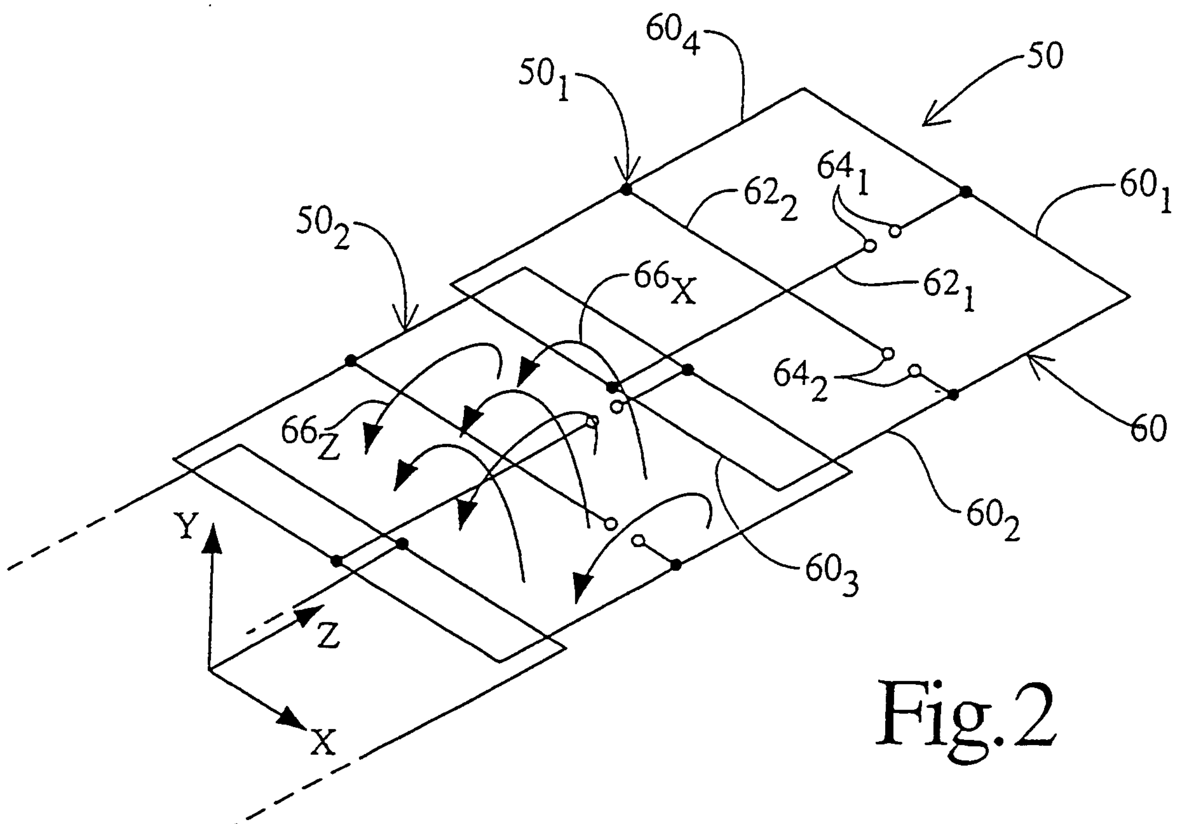
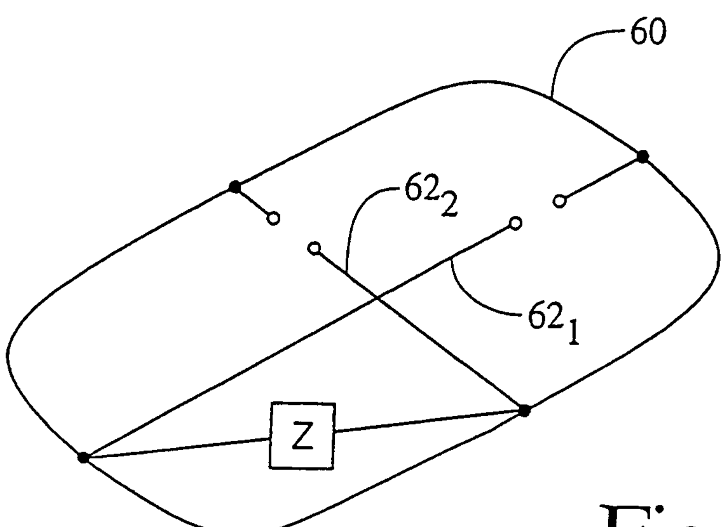

SEQUENCE MEMORY
SEQ. CONTROL
GRAD. FIELD CONTROL
R.F. PULSE CONTROL
TRANSMIT
K
RECEIVER
RECEIVER
RECEIVER
A/D
RECON. PROC.
IMAGE MEMORY
VIDEO PROC.
42
40
26
36
24
34
16
52
54
56
58
59
61
12
10
50
14
B_0
Z
Y
X
50_1
50_2
50_3
50_4
20
30
32
22

Fig. 1



60_4
50_1
50
64_1
62_2
60_1
50_2
66_X
62_1
64_2
66_Z
60
Y
60_2
60_3
Z
X

Fig.2



60
62_2
62_1
Z

Fig.3

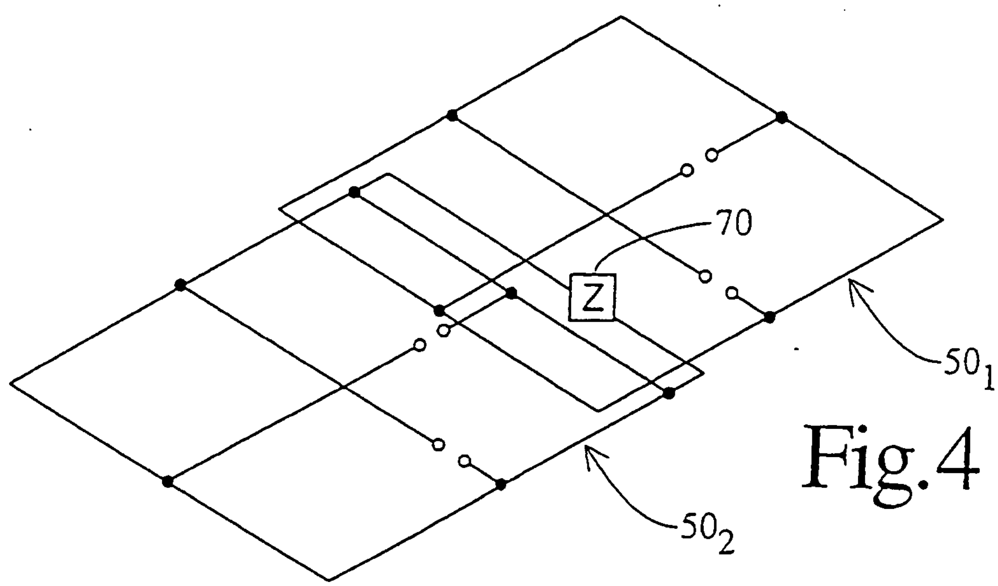


Fig.4

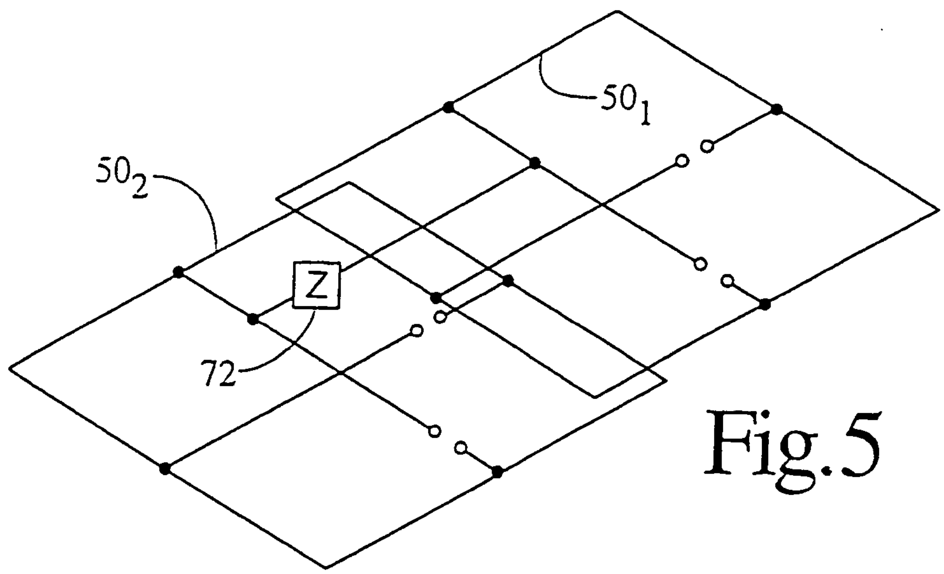


Fig.5

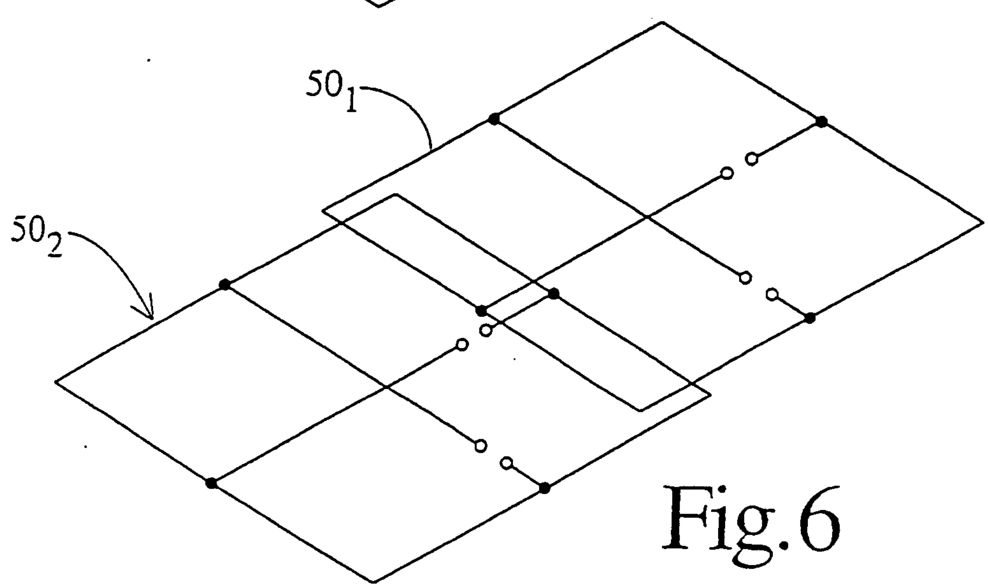


Fig.6

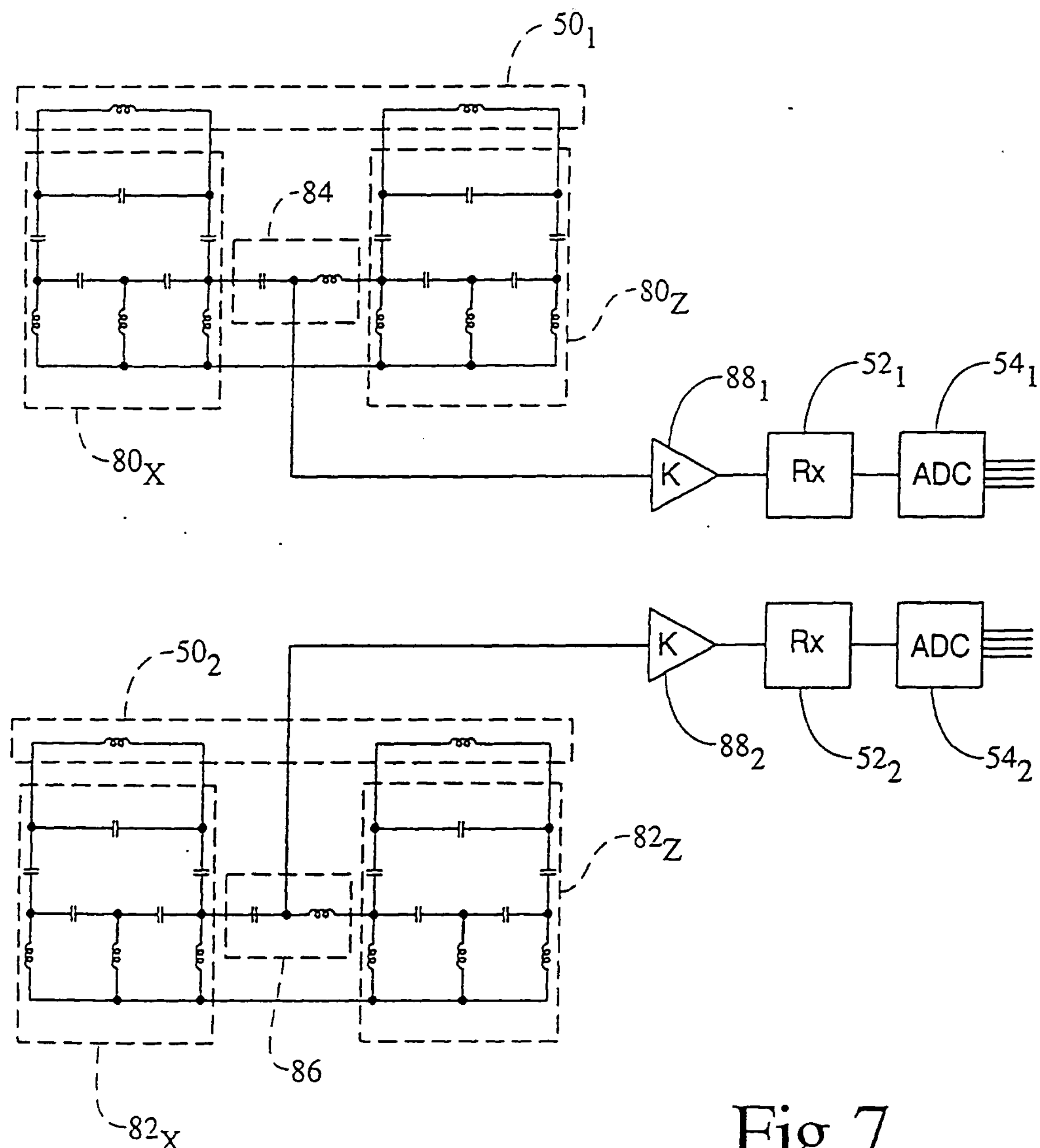
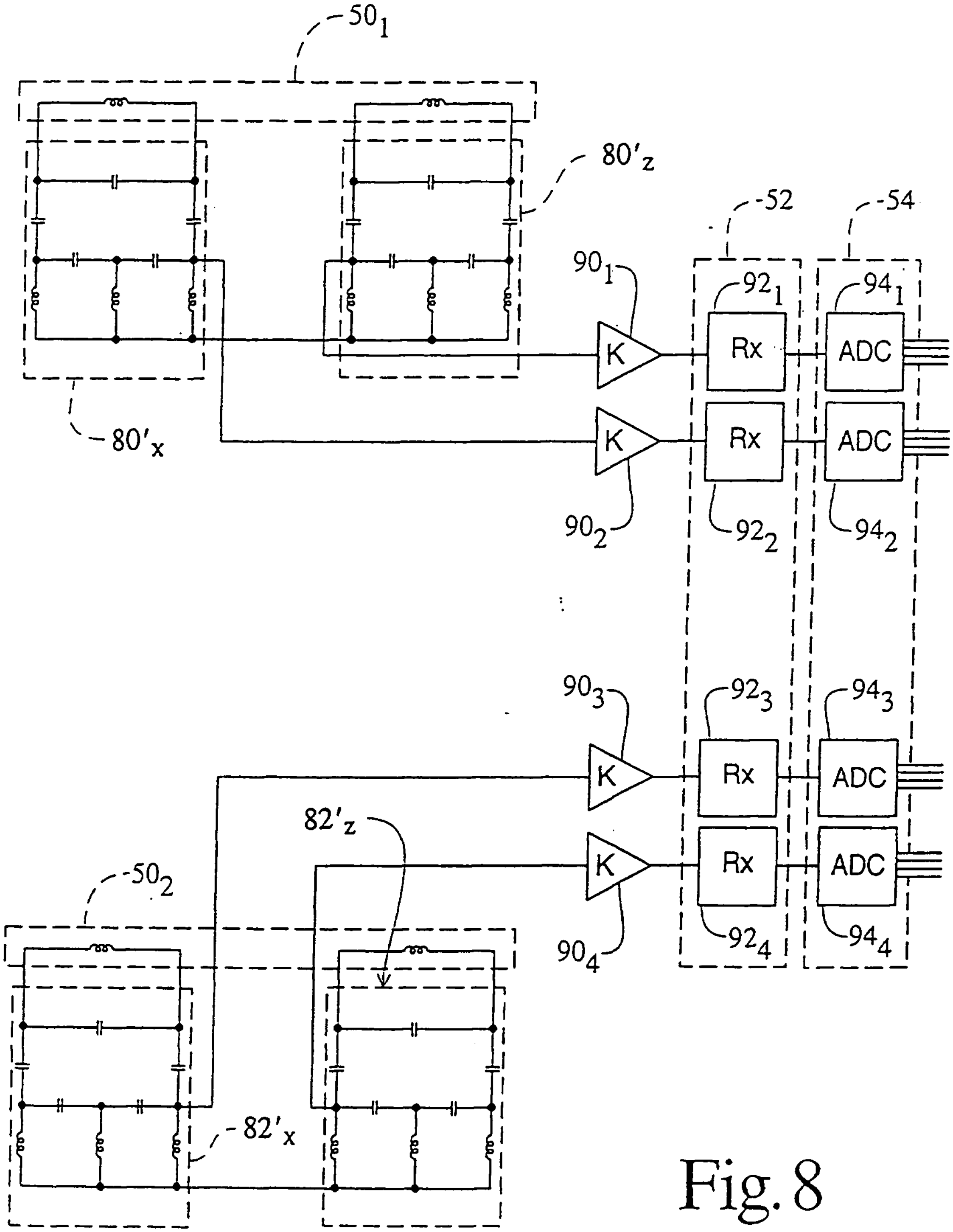

50_1
84
80_Z
80_X
88_1
52_1
54_1
K
Rx
ADC
K
Rx
ADC
50_2
88_2
52_2
54_2
82_Z
86
82_X

Fig. 7



50_1
$80'_z$
-52
-54
90_1
92_1
94_1
K
Rx
ADC
K
Rx
ADC
$80'_x$
90_2
92_2
94_2
90_3
92_3
94_3
K
Rx
ADC
$82'_z$
K
Rx
ADC
-50_2
90_4
92_4
94_4
$82'_x$

Fig. 8

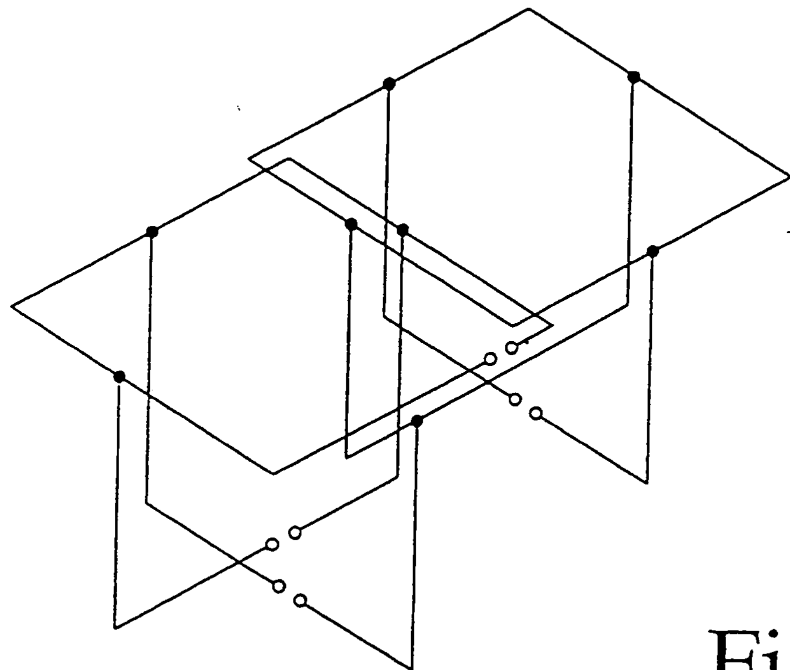


Fig. 9

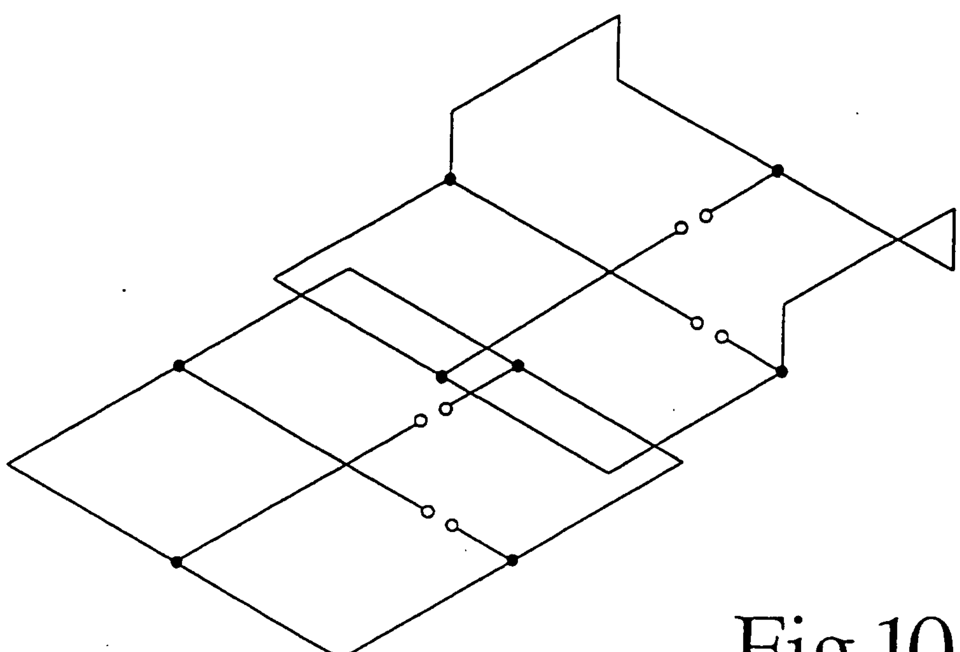


Fig.10

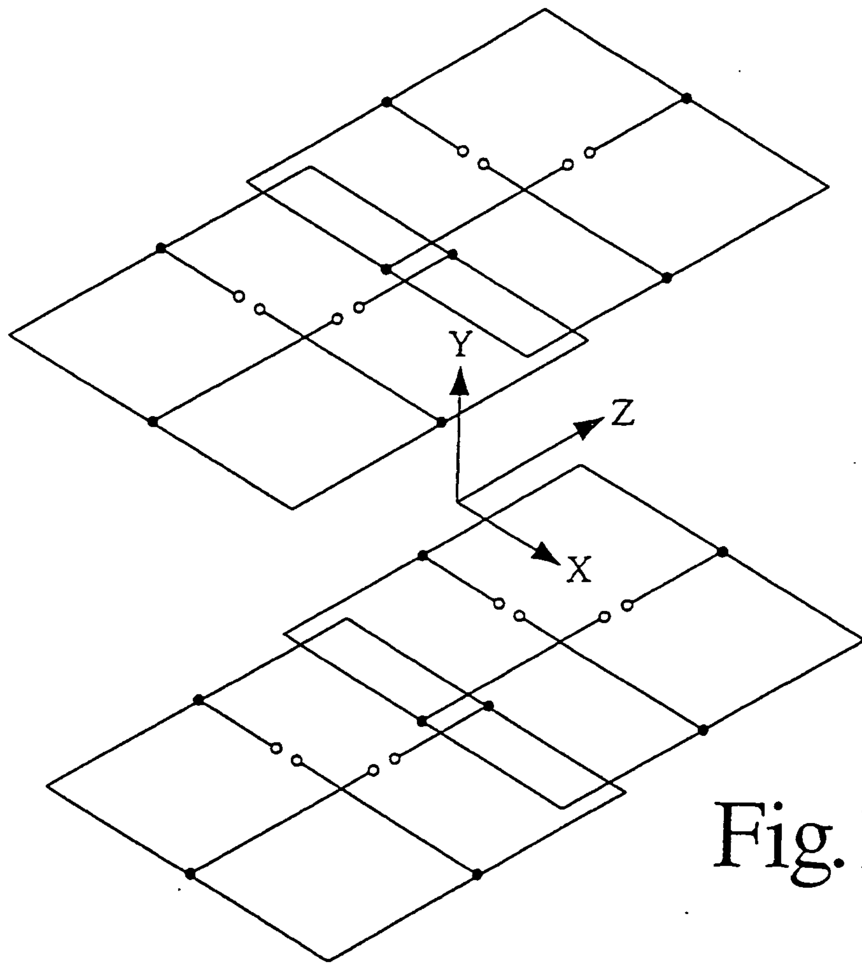


Fig.11

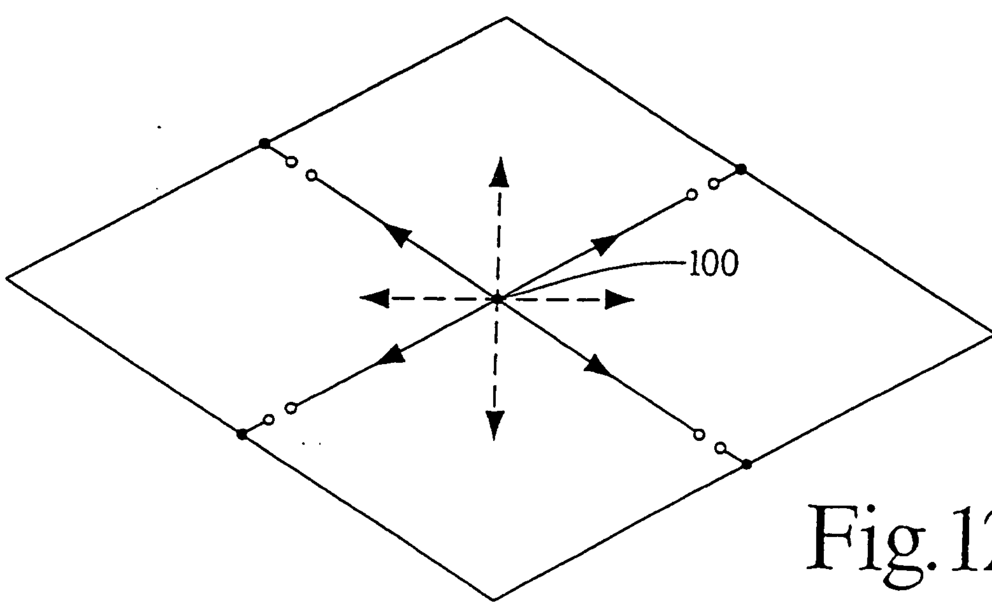


Fig.12

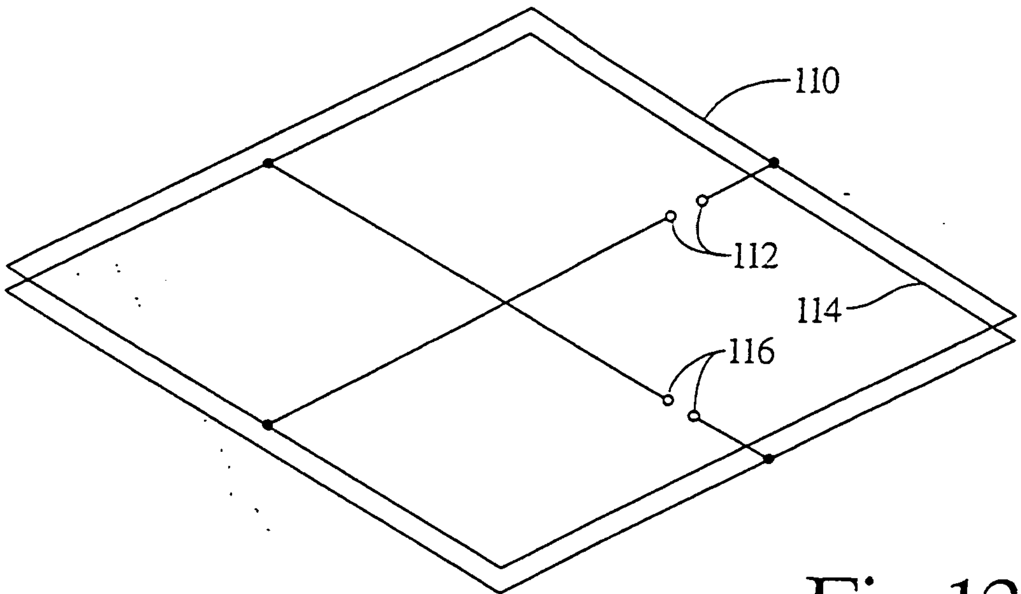


Fig. 13

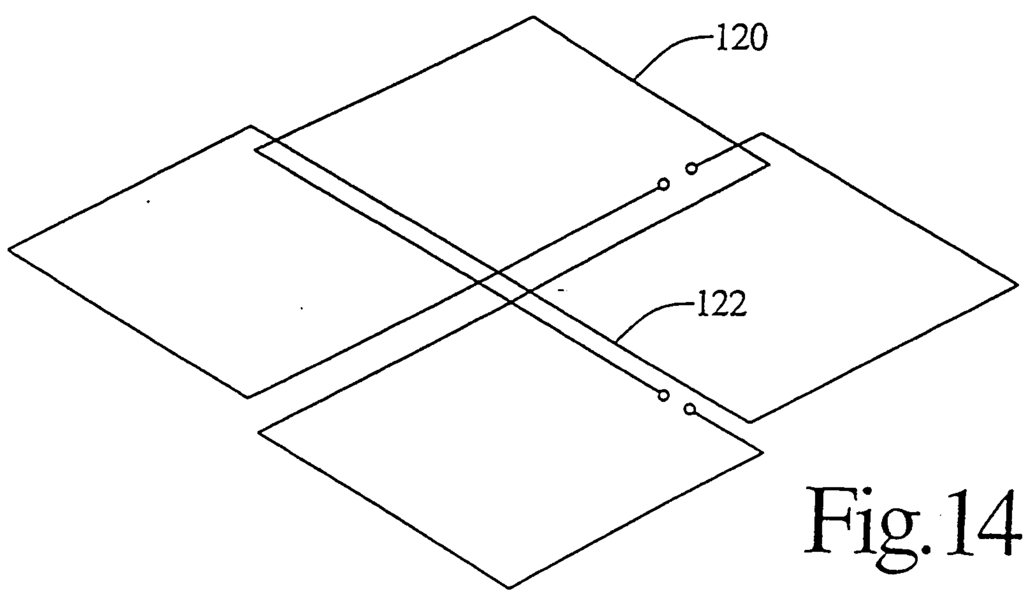


Fig. 14